A Simple, Regional Characterization of Wave-Generated Ripple Geometry and Orientation

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LONG-TERM GOALS

The goal of this study is to provide a simple, regional characterization of wave-generated ripple spacing, height and orientation through time. The approach is being tested against data collected during the Ripple DRI in association with the SAX04 field experiments as well as future Ripple DRI field campaigns.

OBJECTIVES

This project revisits the Wiberg and Harris (1994) method for calculating ripple geometry with three objectives in mind:

1) to review the literature for wave-generated ripple measurements made since our 1994 compilation, compare them to the ripple scalings we developed, and update our model as necessary;

2) to couple the ripple calculations with the SWAN and/or WaveWatchIII wave model to consider the regional-scale spatial and temporal distribution of wave-formed ripples; and

3) extend the wave ripple calculations to include ripple realignment and degradation.

APPROACH

The simple method for estimating wave-generated ripple height and spacing developed by Wiberg and Harris (1994) is being used to estimate ripple characteristics regionally and through time. The method requires near-bed wave orbital diameter, grain size and water depth as input. Wave models such as WaveWatch III and SWAN provide the necessary wave data, and dbSEABED, a marine sediment database, has been used to characterize grain size until site specific data become available. Results are being compared to field measurements of ripple dynamics collected by other members of the Ripples DRI program.

WORK COMPLETED

1) The literature review is essentially complete. All of the original data sets used by Wiberg and Harris as well as the new data sets found in our literature review have been entered into a spreadsheet of ripple data with related wave and sediment parameters. Copies of the list of papers found in our review and the spreadsheet are available on request.

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14. ABSTRACT
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15. SUBJECT TERMS

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2) The ripple calculations have been coupled with the WaveWatch III wave model to consider the regional-scale spatial and temporal distribution of wave-formed ripples during Sep-Nov 2004, coinciding with the SAX04 field experiment. An implementation of SWAN for this time period is close to being complete.

RESULTS

1) Literature review and reassessment of the Wiberg and Harris (1994) ripple model.

We identified over 100 articles related to shallow marine ripples in our literature review. Based on review of abstracts or the full paper, we identified those that provided significant new data sets that include ripple geometry (height and spacing) and corresponding wave conditions. To be consistent with the data sets originally used by Wiberg and Harris, we focused on those sets with 2-dimensional ripples for which the contribution of currents to the total bed shear stress was relatively small. Because the Wiberg and Harris data sets included more laboratory than field data, because field data displayed more variability than lab data and because we are primarily interested in applying the model to field situations, we primarily considered field data or laboratory data from large-scale facilities in which it was possible to approach field conditions. With those constraints, we identified and included 3 new large data sets: Traykovski et al. (1999) – field data from the LEO-15 site; Hanes et al. (2001) – field data from Duck, NC; and Williams et al. (2004) – laboratory data from a large wave flume at Delft Hydraulics. A smaller, laboratory data set (Dumas et al., 2005) focusing on large-scale wave-generated bedforms has also been included. The large data sets are particularly notable because they provided time-series information on the evolution of the ripple fields under changing wave conditions.

The addition of the three new large data sets identified above revealed a distinct ripple type not included in the classification scheme used by Wiberg and Harris (1994). The original scheme classified ripples as orbital (ripple wavelengths proportional to near-bed orbital diameter), anorbital (wavelengths proportional to grain size), or suborbital (transitional between orbital and anorbital ripples). In addition to wavelength, an important distinguishing characteristic of these ripple classes was their steepness (height to wavelength ratio). Orbital ripples have an almost constant, high steepness of ~0.17, while anorbital ripples are less steep, with steepness decreasing as orbital diameter increases for a given grain size, consistent with increasing sediment suspension. The new ripple type has a wavelength proportional to orbital diameter (like orbital ripples), but steepnesses that vary like those of anorbital ripples, but at lower values of the ratio of orbital diameter to grain size (Fig. 1).

This new class of ripples, identified by Hanes et al. (2001) as long wave ripples (LWR) are present in the Hanes et al. (2001) and Williams et al. (2004) data sets. At times these ripples co-exist with short, anorbital ripples (SWR), but often the bed shear stresses are sufficiently high such that upper plane-bed conditions would be expected. Similar bedforms were previously observed by Southard et al. (1990) and further considered in Dumas et al. (2005). Although our analysis is not complete, suspension of sediment within the wave boundary layer appears to be important in the formation of LWR. Williams et al. (2005) have proposed a rationalization of LWR and SWR that we are also considering in our analysis.

The Traykovski et al. (1999) data highlight a second area in which the Wiberg and Harris (1994) model requires revision. They observe orbital ripples at orbital diameter-to-grain size ratios larger than the model would predict. These differ from LWR in that their steepness is consistent with that of orbital ripples (~0.15 for the Traykovski et al. data) rather than anorbital ripples. The grain size at

Traykovski et al.'s field site (LEO-15) was relatively coarse. The persistence of orbital ripples at large relative orbital diameters may indicate that there is insufficient time during a wave period to move enough of this coarser sand for the smaller-scale ripple instability to develop that leads to anorbital ripples.

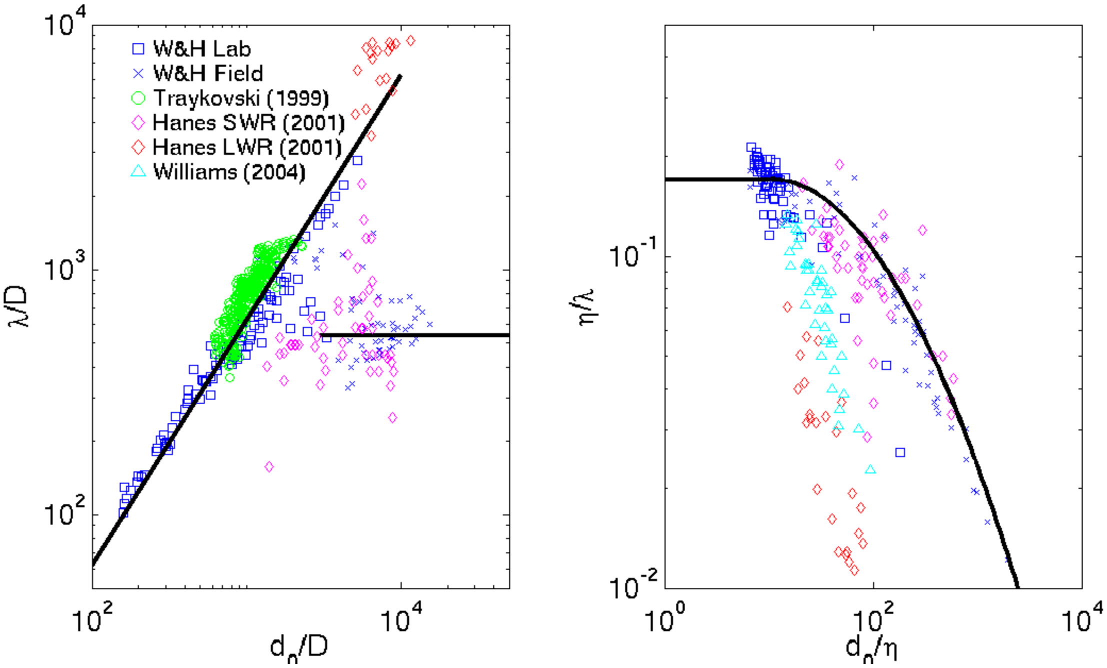

Figure 1. Laboratory and field data for wave-generated ripple wavelength as a function of nearbed wave orbital diameter (both normalized by grain size; left panel) and ripple steepness as a function of orbital diameter over ripple height (right panel). The lines show the limiting cases identified by Wiberg and Harris (1994). The steepness data show that a new category of ripples – long wave ripples – needs to be added to the original set of orbital, anorbital and suborbital ripple classes.

2) Coupled wave field-ripple calculations

The goal of this project is to couple the revised Wiberg and Harris ripple model with a spatially and temporally resolved wave field to predict the evolution of wave-generated ripples in a given region. For general application, the SWAN model nested within WaveWatchIII is likely to produce a wave field with the appropriate resolution that is accurate for relatively shallow water. Other possibilities include Fabrice Ardhuin's CREST model. At present, the spatial wave field has not been fully modeled for the SAX04 field program, though results from the CREST model are expected. In the meantime, I have been working on running SWAN for fall, 2004, at the SAX04 field study area and Bill O'Reilly has run his wave calculations for a set of sites in the field area.

Bed shear stresses estimated from O'Reilly's calculated wave time series along a transect in the SAX04 field area extending from 7 to 18 m water depths for Sep – Nov 2004 are shown in Fig. 2. The horizontal line at a bed shear stress of 0.2Pa is roughly the critical shear stress for initiating motion of medium sand (~0.35mm), which is in the general range of grain sizes in the area. The upper horizontal line in Fig. 2 is the condition for significant suspension of that sand size. The time series indicates that during the largest wave event (Hurricane Ivan), sediment would have been suspended over most of this transect. As the flows waned, ripples would have formed and then relatively quickly become inactive

as the shear stresses decreased below critical values. Subsequently, stresses at the shallow end of the transect (7 m) were large enough to move sediment on 4-7 more occasions, while at the deep end of the transect it is likely that the ripple were never active again during this period. Ripple wavelengths calculated using the Wiberg and Harris (1994) formulation vary between 20 and a little over 30 cm. This is shorter than the observed wavelengths of roughly 50 cm.

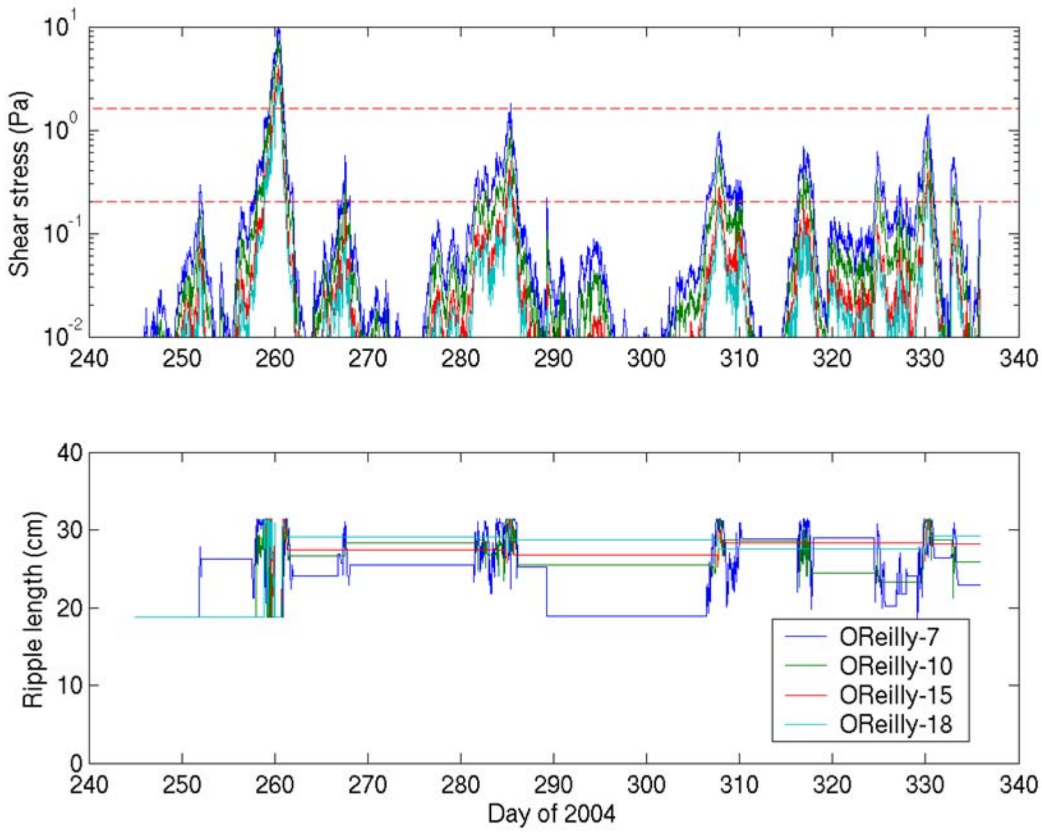

Figure 2. Calculated bed shear stresses (upper panel) and ripple wave lengths (lower panel) for the wave conditions estimated by O'Reilly along a transect through the SAX04 study area. The numbers in the legend refer to the water depth for each calculation. The horizontal bars in the top panel indicate the critical shear stress for initial motion (lower line) and suspension (upper line) of 0.35-mm sand.

Preliminary calculations coupling the ripple model with a spatial wave field were carried out with WaveWatch III as no higher-resolution wave fields for the study area are yet available. Because of the coarse resolution of the model and the fact that it doesn't capture shallow water waves very well, the preliminary calculations were made for a relatively large region of the northwest Florida shelf. Calculations were completed for Sep – Nov 2004, corresponding to the SAX04 field study. Hurricane Ivan occurred during this period and was the only wave event to affect the whole shelf. Calculated bed shear stresses during the peak of Hurricane Ivan are shown in Fig. 3 (left panel). In the green and orange regions, bed shear stresses are large enough to transport sediment and form ripples. After the hurricane, high bed shear stresses were confined to relatively shallow water and ripples that formed in deeper water would become relict and slowly degrade. The direction of the waves, indicated by the arrows, should reflect ripple orientation. Ripple class is contoured in Fig. 3 (right panel; see legend for ripple class designations) for the peak of Hurricane Ivan. All classes of ripples are present and active

at this time. Within 6 hours, wave conditions diminished somewhat (Fig. 2) and the ripples in each location generally shifted down by one class.

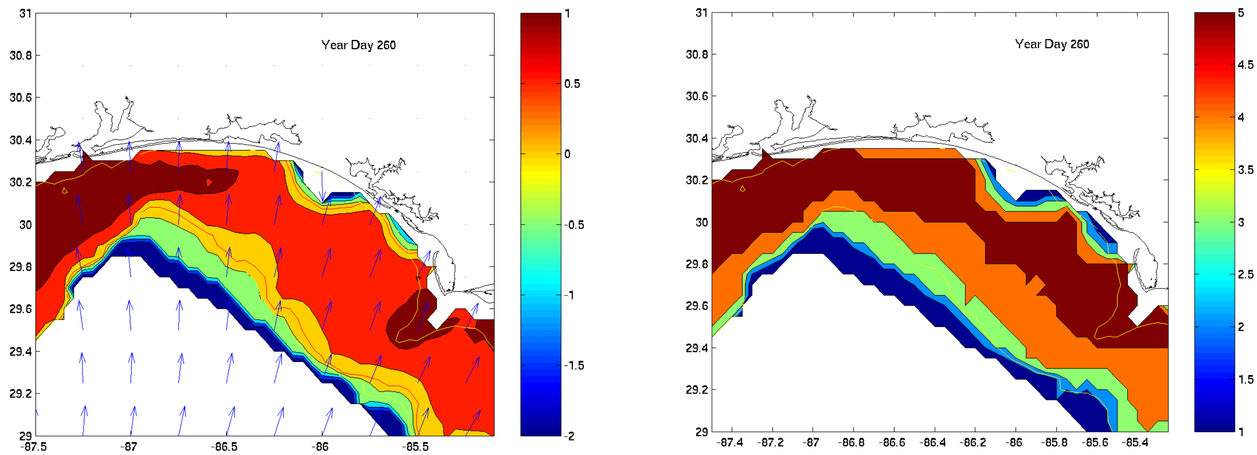

Figure 3. Bed shear stress (left panel, scale in log_{10} of stress) and ripple type (right panel) during the peak of Hurricane Ivan. Bed stresses in colors other than blue are above the threshold of motion for 0.35 mm. Ripple classes: 1=none or relict; 2=orbital; 3=suborbital; 4=anorbital; 5=significant suspension. Six hours after the peak, each ripple type shifted down roughly one class.

Planned work during FY06 includes modifying the Wiberg and Harris (1994) ripple formulation to include long wave ripples, coarse-grained orbital ripples, ripple degradation and reorientation, running it with a high-resolution wave field for the SAX04 study area and comparing the results with the measurements of Hanes, Traykovski, and Hay.

IMPACT/APPLICATION

Improve characterizations of bottom roughness by providing spatial and temporal information about the size and orientation of wave-generated ripples on the seabed, which have been shown to significantly affect the depth of penetration of acoustic signals into the seabed.

RELATED PROJECTS

This work is a direct outgrowth of my work on characterizing environmental forcing conditions in the Mine Burial Prediction program.

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